



Secondary Fusion Reactions in the Mechanical Adiabatic Compression of a Dense Plasma

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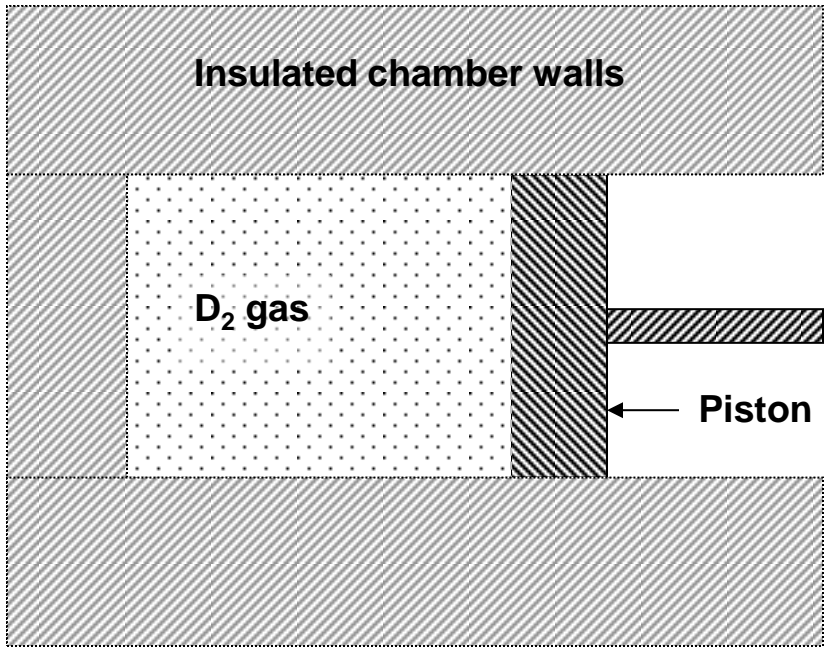
Abstract

We consider fusion processes initiated by the rapid adiabatic compression by a piston of a deuterium plasma contained in a well-insulated chamber. To exploit the n^2 factor in the fusion reaction rate, we consider one mole of deuterium which, at ambient temperature and pressure, provides a particle density of $\sim 10^{19} \text{ cm}^{-3}$. The reaction rate is enhanced by the application of magnetic and electric fields to reduce the number of degrees of freedom of the gas, thereby lowering its heat capacity and producing a higher temperature increase for a given energy input. Previous studies have shown that the combination of adiabatic operation, high particle density and reduced degrees of freedom can result in appreciable fusion rates at temperatures lower than those in magnetic confinement experiments. The prior work considered only primary D-D fusion reactions while the present work also includes D-T reactions. Conditions of energy-break-even and excess energy release were found at temperatures of the order of 10^6 K .

Proposed Method

Exploit n^2 factor and reduced degrees of freedom and perform under adiabatic conditions \Rightarrow appreciable fusion rates at lower temperatures than in standard methods.

Mechanical adiabatic compression



Dense gas of D_2 undergoes adiabatic compression. Rapid process - - explosively driven. Well-insulated chamber – retain energy internally.

Starting conditions One mole D_2 at room P and T.

Apply compression. T increases. D_2 molecules $\rightarrow D_2$ atoms $\rightarrow D_2$ atoms ionize \rightarrow deuteron-electron plasma \rightarrow Fusion of deuterons.

Assumptions. Make simplifying assumptions. Reversible adiabatic compression Apply equilibrium thermodynamics Treat as *van der Waals* (vdW) gas: $(P + aN^2/V^2)(V - Nb) = RT$

Degrees of freedom γ = specific heat ratio Relate to degrees of freedom f of the gas: $\gamma = (f + 2) / f$. For monoatomic gas: $f = 3$ Deprive particles of freedom of motion \Rightarrow larger T increase for a given energy input. Accomplish with (1) External magnetic field(s) (2) Electric discharge in direction of piston motion. Also \Rightarrow Pinch Effect.

Adiabatic compression of a vdW gas

$$T = T_0 \left(\frac{V_0 - Nb}{V - Nb} \right)^{\gamma-1} = T_0 \left(\frac{\beta(V_0 - Nb)}{V - \beta Nb} \right)^{2/f}$$

$$W = - \int_{V_0}^V PdV = \frac{NRT_0 f}{2} \left[\left(\frac{\beta(V_0 - Nb)}{V_0 - \beta Nb} \right)^{2/f} - \beta^{-2/f} \right] - \frac{aN^2}{V_0} (\beta - 1).$$

Work to compress a vdW gas

Nuclear fusion reactions

Primary: $D + D \rightarrow T + p + 4.03 \text{ MeV}$ (T = tritium)
 $D + D \rightarrow {}^3\text{He} + n + 3.27 \text{ MeV}$

Secondary: $D + T \rightarrow \alpha + n + 17.6 \text{ MeV}$
 $D + {}^3\text{H} \rightarrow \alpha + p + 18.3 \text{ MeV}$

Energy release

Primary reactions occur with \approx equal probability o
1st secondary reaction has much higher probability than 2nd.

Energy release in time Δt : $\Delta E = r Q V \Delta t$.
 $Q = av'g$ reaction energy release/reaction ; r = computed reaction rate

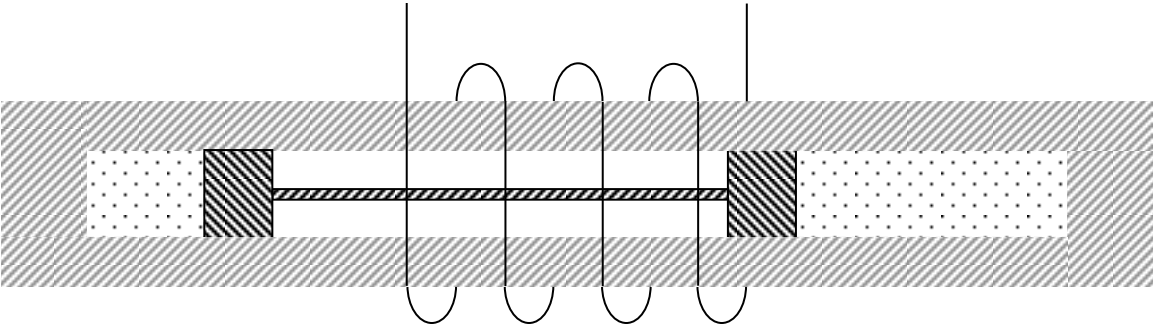
Simplification Assume fusion occurs only at maximum compression and that One-half of deuterons react in primary D-D reactions; Half of these result in formation of T; These T react with the remaining D.

Calculate $\Delta E / W$ for $\beta = 100, 125, . f = 3, 2, 1, \Delta t = 1 \text{ ms}$,
 β = compression factor, f = no. degrees of freedom.
Best results
 $\beta = 100, f = 1: \Delta E / W \approx 1; T \approx 5 \times 10^6 \text{ K}$
 $\beta = 125, f = 1: \Delta E / W \approx 50; T \approx 9 \times 10^6 \text{ K}$.

Note: Energy Break-Even at $T \approx 5 \times 10^6 \text{ K}$
Excess energy at $T \approx 9 \times 10^6 \text{ K}$.

Applications

Single shot: Neutron source to initiate fission.
Multiple compressions in dual chambers – reciprocating engine.
Surround with coil to extract energy.



Summary and Conclusions

Exploited effects of n^2 factor and reduced degrees of freedom. Adiabatic conditions \Rightarrow energy retained internally. Obtained energy break-even and excess energy at temperatures lower than in standard fusion methods

To be more realistic:
Not all input energy serves to compress gas. Must consider particle losses via leakage. Compensated by ignoring:
Pinch Effect.
Enhancements: Deuterated walls; Screening effects of electrons.

References

David W. Kraft, *Nuclear Fusion by Mechanical Adiabatic Compression of a Dense Plasma*, Proceedings of the 13th International Conference on Emerging Nuclear Energy Systems, ICENES 2007, İstanbul/Türkiye (3 – 8 June 2007) S. Şahin (Ed.) ISBN-978-975-01805-0-7.
David W. Kraft and Robert G. Butler, *Multistage Fusion Reaction Rates In An Adiabatically Compressed Plasma*, Transactions of Fusion Science and Technology **61**, 475 (2012).
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